Enhancement of Efficiency of Operation of High-Speed Aircraft Engine Elements by Means of Separation Flow Controlling

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Results of investigations of the mechanism of appearance and destruction of separation zones in supersonic gas flows are presented. Methods for controlling separation phenomena were developed to increase the operation efficiency of ducts, combustors, inlets and outlets of high-speed aircrafts.

The main trends of investigations were:

1) Study of deceleration flows in ducts of various shapes with pseudoshock;

2) Development of non-traditional manners of spatial implementation of combustion in supersonic flows;

3) Computational analysis of optimum methods of energy supply in internal flows with separation zones;

4) Control of separation phenomena for increasing efficiency of power plant outlets.

The following major results were obtained:

For 1st trend:

Features of the structure of the non-steady separation in the ducts with deceleration of the supersonic flow in the pseudoshock were determined.

Methods for controlling the pseudoshock were developed.

Conditions for forming separation zones under interference of various shear layers (vortex, jet) generated ahead of the entrance and in ducts with the pseudoshock were studied.

For 2nd trend:

For the first time in the world practice the gasdynamic stabilizers of combustion were developed. Their principle of operation was based on artificial generation of free-hanging separation zones in the supersonic flow. Successful experimental try-out of some schemes of gasdynamic stabilizers was carried out at the TsAGI's hypersonic test rig T-131 at M=2.5 - 2.6. They permitted to obtain self-ignition and stable combustion of hydrogen:

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- in the local bow subsonic zone which was produced as a result of interference of the sonic gas jet with the strong shock wave;
- in the bow subsonic zone arising under flowing around the axisymmetric shaped non-started ducted body with the central hollow needle through which the gas jet was ejected upstream. The needle protruded before the diffuser edge at the length of L=0.28…1.28D (where D was the diameter of the diffuser entrance);
- in the free-hanging subsonic zone arising as a result of interference of coaxial jets of fuel and air behind the first barrel of the off-design air jet flowing out from the body with the passage.

For the aerated hydrocarbon fuel the scheme of the gasdynamic stabilizer was experimentally verified. The stabilizer ensured the self-ignition and combustion of the fuel in the pilot torch arising behind the first barrel of the off-design jet of the fuel-air mixture flowing out from the body with the passage.

For 3rd trend:

The semi-empirical procedure for calculation of hydrocarbon fuels combustion was developed. The efficiency of various manners of the fuel supply to the duct with generation of both global and local separation zones in the wall region was analyzed. Influence of the type of separation zones on efficiency of the working process in the supersonic combustors was estimated.

The mathematical model of processes of the ignition and combustion in three-dimensional statement was proposed taking into account zones of combustion stabilization. The mathematical model was based on the averaged Navier-Stokes equations supplemented with the model of turbulent viscosity and the detailed scheme of the chemical kinetics.

For 4th trend:

The concept of the artificial generation of separation zones was developed to increase the efficiency of high-speed aircraft outlets. The features of change of characteristics of supersonic and hypersonic nozzles were considered taking into account the influence on losses of friction thrust, chemical non-uniformity and conicity of the flow.

The practical application of the obtained fundamental results is aimed at:

1) Improvement of inlets and isolators of advanced supersonic air-breathing engines;
2) Creation of high-effective combustors of advanced supersonic air-breathing engines operating over the wide range of speeds and flight altitudes;
3) Choice of optimum manners of fuel supply to the combustor of high-speed ramjets and increase of their thrust-economic characteristics;
4) Increase of efficiency of supersonic and hypersonic nozzles.